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Circinella (*Mucorales, Mucoromycotina*) from China

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Abstract—Nine taxa representing the genus *Circinella*—*C. angarensis*, *C. minor* var. *minor*, *C. minor* var. *asperior*, *C. mucoroides*, *C. muscae*, *C. nodulosa* sp. nov., *C. ramosa* sp. nov., *C. simplex*, *C. umbellata*—were recorded and described or redescribed from twenty-four different localities in seventeen cities of fifteen provinces in China. A key is provided to the nine taxa recorded from China. No zygosporic state was formed between any pair of the isolates studied.

Key words—*Mucoraceae*, morphology, new species, taxonomy

Introduction

Circinella (van Tieghem & Le Monnier 1873) is one of the smaller genera of the family *Mucoraceae* (*Mucorales*, *Mucoromycotina*). It is closely related to *Mucor* but differs in forming sporangiophores with circinate branches bearing sporangia with persistent walls rather than the non-circinate branches and non-persistent sporangial walls characteristic of *Mucor* species (Hesseltine & Fennell, 1955).

Hesseltine & Fennell (1955) recognized eight species in *Circinella*. Although subsequently seven additional species were included (Faurel & Schotter 1965; Mil'ko 1968, 1969, 1974; Patil & Kale 1981; Arambarri & Cabello 1996), six have since been accepted as representing other genera such as *Fennellomyces*, *Gongronella*, *Lentamyces*, *Mucor*, and *Pirella* (Benny & Benjamin 1975, Benny & Schipper 1992, Walther et al. 2013).

Six *Circinella* species have been described in Taiwan: *C. minor*, *C. mucoroides*, *C. muscae*, *C. rigida* [° *Mucor durus*], *C. simplex*, and *C. umbellata* (Yang & Liu 1972, Xiao et al. 2013).

In Mainland China, R.Y. Zheng isolated and identified *Circinella angarensis*, *C. minor*, *C. muscae*, and *C. umbellata*, which had been listed (but not described or illustrated) in Teng (1964) and Tai (1979). We collected and identified additional *Circinella* strains, adding four taxa (including two new species) to the Chinese records.

Of the nine *Circinella* taxa found in China described or redescribed in detail and illustrated here, eight have been recorded from Mainland China and one only from Taiwan.

Materials & methods

Isolation

All strains found in China were isolated from soils, dung, or rotten materials. The Warcup (1950) dilution plate method was used for soil samples, a small part of each dung sample was soaked in sterilized distilled water for 5–6 hours before using different dilutions to pour plates, and rotten materials were placed directly on the media.

Cultures

The isolates of each taxon studied are listed after the description of that taxon. Our research group isolated and identified the strains from Mainland China, and Prof. Hsiao-Man Ho supplied those from Taiwan. Dr. K. O'Donnell kindly supplied cultures from NRRL for comparative studies; Dr. A. Nakagiri kindly supplied culture NBRC 4453, sent by Dr. H. Naganishi. Living cultures are maintained in the Culture Collection of the State Key Laboratory of Mycology (accession numbers prefixed with 'C') and the China General Microbiological Culture Collection Center (CGMCC), and dried cultures are deposited in the Herbarium Mycologicum Academiae Sinicae (HMAS), all of the Institute of Microbiology, Chinese Academy of Sciences, Beijing, China.

Media & cultivation

SMA (modified synthetic *Mucor* agar, containing dextrose 20 g, asparagines 2 g, KH_2PO_4 0.5 g, $MgSO_4 \cdot 7H_2O$ 0.25 g, thiamine chloride 0.5 mg, agar 20 g in 1000 mL distilled water, pH 7) was used for morphological studies. Color codes cited in the descriptions follow to Ridgway (1912). PDA, also adjusted to pH 7, was used for isolation, establishing temperature–growth relationships, and mating experiments. Cultivation period and temperature were 4–7 days at 18°C for isolating, 4–14 days at 25°C for morphological studies, 4 days at temperatures of 32–43°C for determination of the maximum growth temperature, and 7–20 days at 18°C for mating experiments.

Results & discussion

Maximum growth temperature

The 45 living cultures studied were tested twice for their maximum growth temperature. The eight species have a very similar maximum growth range: (31–)36–40°C, which may reflect the close affinity among these taxa. The number of strains is, however, too small to summarize the exact range for each taxon. Since the results obtained are not distinctive enough to differentiate one another, the maximum growth temperature is not suitable for use in the identification of taxa in this study.

Mating experiments

Zygospores were not produced under different conditions between any of the mating pairs.

Morphological studies

As noted for many taxa in other mucoralean genera, morphological characteristics are found to be useful taxonomic criteria in distinguishing taxa within *Circinella*.

Taxonomy

Circinella Tiegh. & G. Le Monn., Ann. Sci. Nat., Bot., 5e sér., 17: 298. 1873.

Colonies fast growing, filling the Petri dish in 7–9 days at ±25°C, (3–) 7–10 mm high, at first white, then blackish in one week due to formation of sporangia; reverse occasionally wrinkled; with or without an unpleasant odor. Sporangiophores circinate, often in groups and borne alternately at the both sides of the main stems of the sporangiophores. Sporangia borne at the tip of the circinate branches, many-spored. Columellae well developed, variously shaped, always with a well-defined collar. Sporangiospores numerous, hyaline, globose to ovoid, always single-celled. Chlamydospores absent. Zygosporic state not found. (According to Hesseltine & Fennell (1955), zygosporangia [as "zygospores"] are nearly smooth-walled and produced between more or less equal and unadorned suspensors on special zygophores.)

Key to *Circinella* taxa recorded from China

1. Sporangiospores >10 µm diameter .... ***C. angarensis***
1. Sporangiospores <10 µm diameter 2

2. Sporangiospores angular and irregular in shape .... ***C. simplex***
2. Sporangiospores neither angular nor irregular in shape 3

3. Sporangia resistant to breaking; old colonies usually blackish grey .... *C. rigida* [= ***Mucor durus***]
3. Sporangia easy to break; old colonies usually brownish 4

4. Sterile spines present on the sporangia-forming branches 5
4. Sterile spines absent on the sporangia-forming branches 6

5. Apex of columellae smooth .... ***C. minor*** var. ***minor***
5. Apex of columellae verrucose .... ***C. minor*** var. ***asperior***

6. Umbels with 2–12 sporangia .... ***C. umbellata***
6. Umbels with 4–5 sporangia 7

7. Sporangiophores slightly undulate .... *C. mucoroides*
7. Sporangiophores not undulate 8
8. Not forming special structures at the base of spines .... *C. muscae*
8. Forming special structures at the base of spines 9
9. Special structures nodulose, not branched .... *C. nodulosa*
9. Special structures not nodulose, branched .... *C. ramosa*

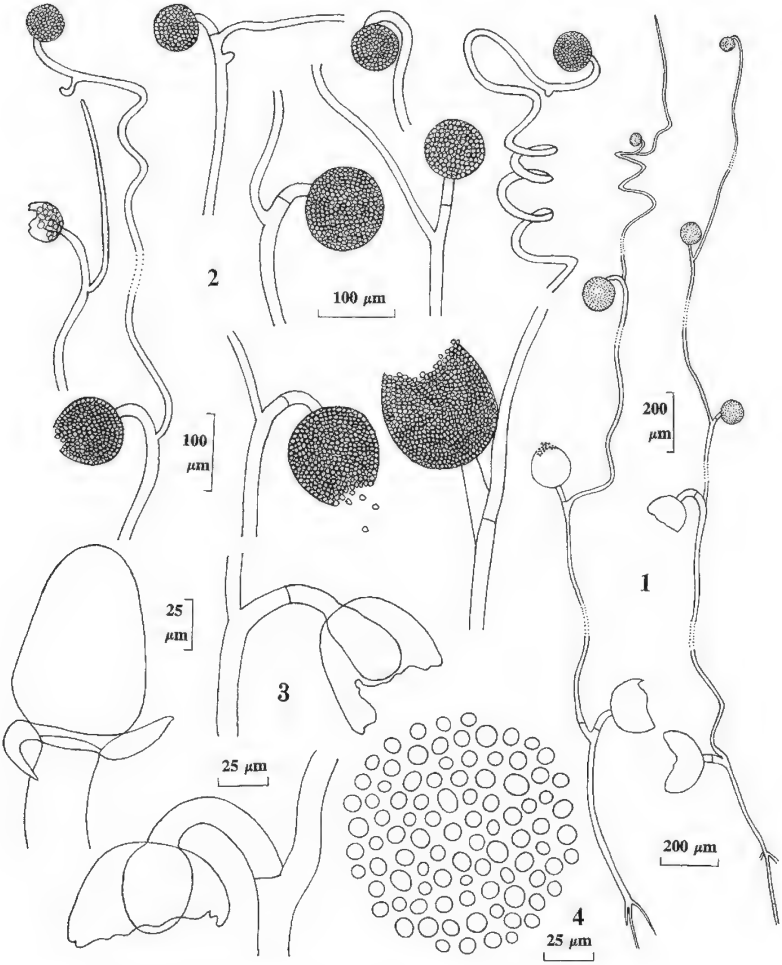

Fig. 1. *Circinella angarensis* (C43). 1. General characteristics of the sporophores; 2. Terminal portion of the sporangiophores; 3. Columellae with small or more often large pieces of the basal part of the sporangial wall attached;. 4. Sporangiospores.

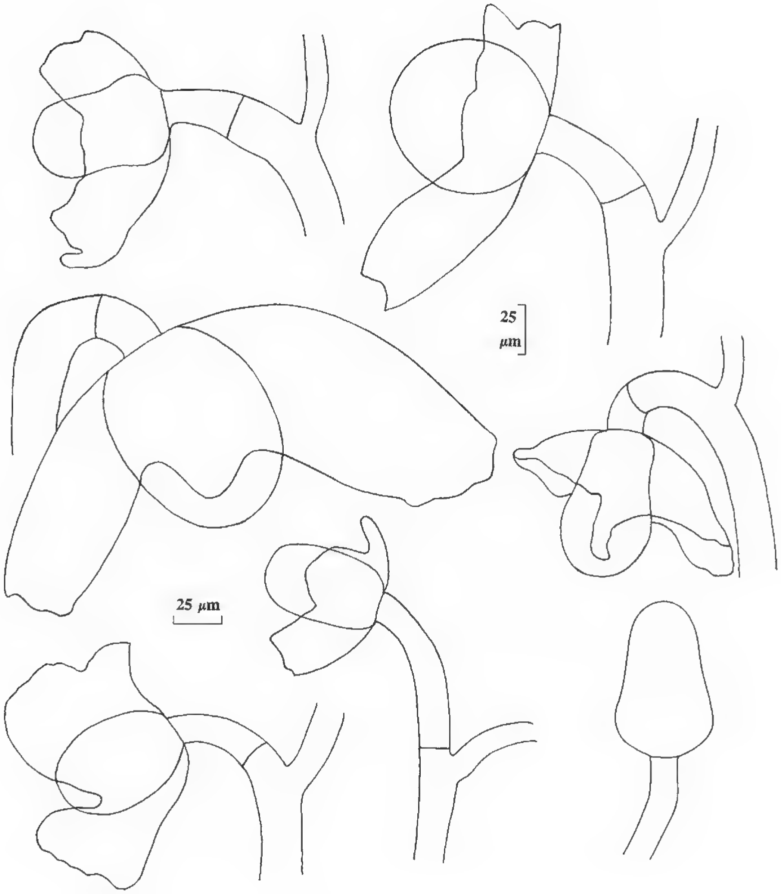

Fig. 2. *Circinella angarensis* (C43). More columellae with large pieces of sporangial wall attached.

Circinella angarensis (Schostak.) Zycha,
Krypt.-Fl. Brandenburg 6a: 98. 1935. Figs 1, 2
≡ *Mucor angarensis* Schostak., Ber. Deut. Bot. Ges. 15:473. 1897.

Colonies floccose, growing well at ±25°C, 6.8 cm in diameter and reaching 15 mm high on PDA, but 3.5 cm in diameter and 10 mm high on SMA. Odor none. At first white, then Light Drab to Cinnamon Drab or Buffy Brown, reverse Light Drab, margin irregular. Rhizoids present. Sporangiophores arising from both substrate and aerial mycelia, sub-straight to helicoid, main stems

11.5–24.5 μm diam., branches 6–10 μm diam., brownish colored, growing indefinitely and branching sympodially, branches with 1–2 sporangia, often accompanied by a spine. Lateral branches circinate, single or united into whorls and branching sympodially, branches with 1–2 sporangia, often accompanied by a spine. SPORANGIA (53–)83–145(–160) μm diam., at first hyaline, then blackish, with spores visible inside the sporangium, deliquescing after broken. COLUMELLAE ovoid and 61–82 × 44–60 μm, broadly cylindrical and 76 × 71 μm, cylindrical and 66–98.5 × 49–70 μm, nearly globose and 39–65 μm diam. SPORANGIOSPORES globose and 6–11 μm diam., or ovoid and 6.5–12 × 6–9.5 μm. CHLAMYDOSPORES absent. ZYGOSPORIC STATE not formed between any pair of the (+) and (–) strains found in China under different conditions.

STRAINS STUDIED: CHINA, BEIJING, Beijing Zoo, from dung of a special kind of pig, 30 April 1964, Zhe-fang Han (C43 = CGMCC 3.3396). USA, CALIFORNIA, from rodent dung (C31 [= CBS 172.62 = NRRL 2628]); Los Angeles County, San Gabriel Mountains, from dung, R.K. Benjamin (C30 [=NRRL 2410, NT of *Mucor angarensis*]).

Circinella angarensis, originally described as *Mucor angarensis* by Schostakowitsch (1897), is recognized by having larger sporangia, columellae, and sporangiospores than other *Circinella* species. Zycha (1935) transferred this taxon to *Circinella* based on its original description. Hesseltine & Ellis (1961), who re-examined its isolates, confirmed this combination and proposed NRRL 2410 as neotype.

Circinella minor Lendn. var. ***minor***, Bull. Herb. Boissier, 2e sér., 5: 199. 1905. FIG. 3

COLONIES floccose, growing well at ±25°C, 2–5(–10) mm or even higher; at first white, then Light Drab to Cinnamon Drab or Buffy Brown, reverse Light Drab SPORANGIOPHORES erect, main stems 8–18.5(–32) μm diam., branches 4–9(–14) μm diam. and 59–450 μm in length. SPORANGIA spherical, terminal ones (41–)57–82(–117) μm diam., lateral ones 29–70(–80) μm diam. COLUMELLAE broadly ovoid, pyriform or other shape, (27–)36–63(–99) × (20–)31–47(–68) μm, applanate or hemi-spherical, (7–)13.5–45 × (9–)16–63 μm. SPORANGIOSPORES spherical and 3.5–7(–9) μm diam., or ovoid and 4.5–7(–11) × 3.5–6.5(–9.5) μm,, hyaline. CHLAMYDOSPORES absent. ZYGOSPORIC STATE not formed between any pair of the (+) and (–) strains found in China under different conditions.

STRAINS STUDIED: CHINA, SHANXI, Datong, from dung of black bear in zoo, 21 August 1963, Fu-mei Hu (C3 = CGMCC 3.14087); from horse dung, Fu-mei Hu (C16 = CGMCC 3.14100). BEIJING, Zoological Institute, from cat dung, 3 August 1960, Hu Fu-mei (C8 = CGMCC 3.14092). HUNAN, Hengyang City, Yueping Park, from soil, 17

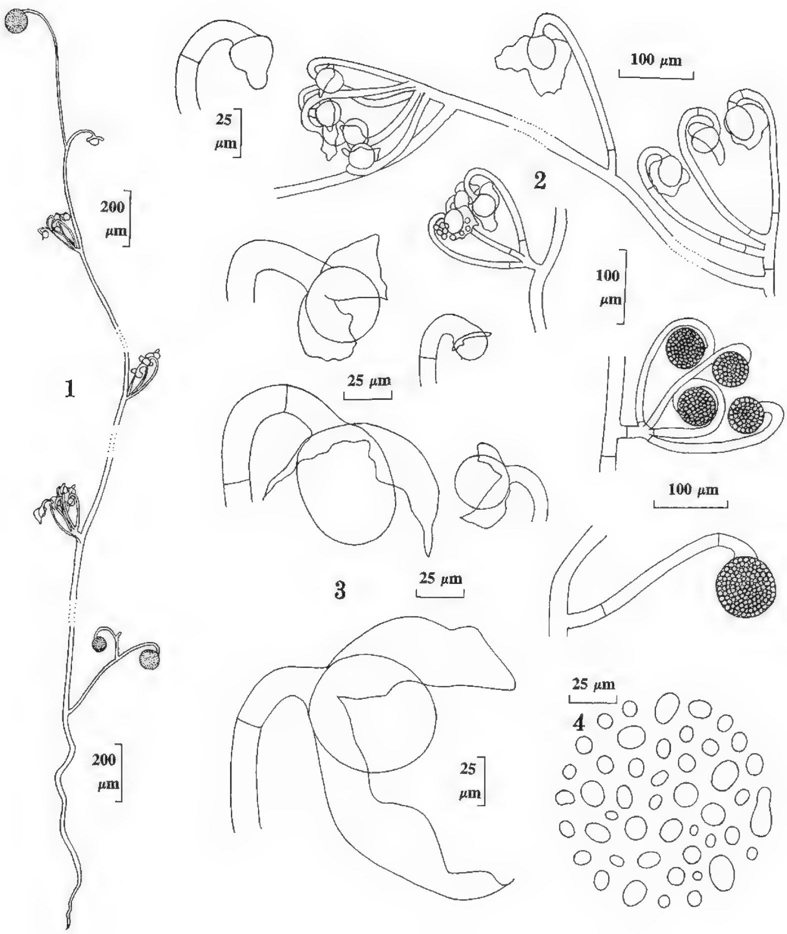

FIG. 3. *Circinella minor* var. *minor* (C3). 1. General characteristics of the sporophores; 2. Terminal portion of the sporangiophores; 3. Columellae often with large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

June 1963, Ru-yong Zheng & Fei-mei Hu (C11 = CGMCC 3.14095). **UNKNOWN**, A.F. Blakeslee (C32 [= NRRL 1353, = CBS 143.56]).

Circinella minor differs from other *Circinella* species in producing sporangiophores that terminate in an umbel of (1–)2–4(–6) sporangia and lacking a spine.

Circinella minor var. ***asperior*** M.O. Reinh.,

Ber. Deutsch. Bot. Ges. 45: 131. 1927. FIG. 4

COLONIES floccose, growing well at ±25°C, (2–)3–8(–10) mm high, at first white, becoming Old Gold at the 7th day, reverse milky white with pale brownish tint to Pale Orange Citrine, usually with disordered patches. Odorless, some nearly odorless. STOLONS and RHIZOIDS absent. SPORANGIOPHORES arising from the substrate or aerial mycelia, erect, growing indefinitely and

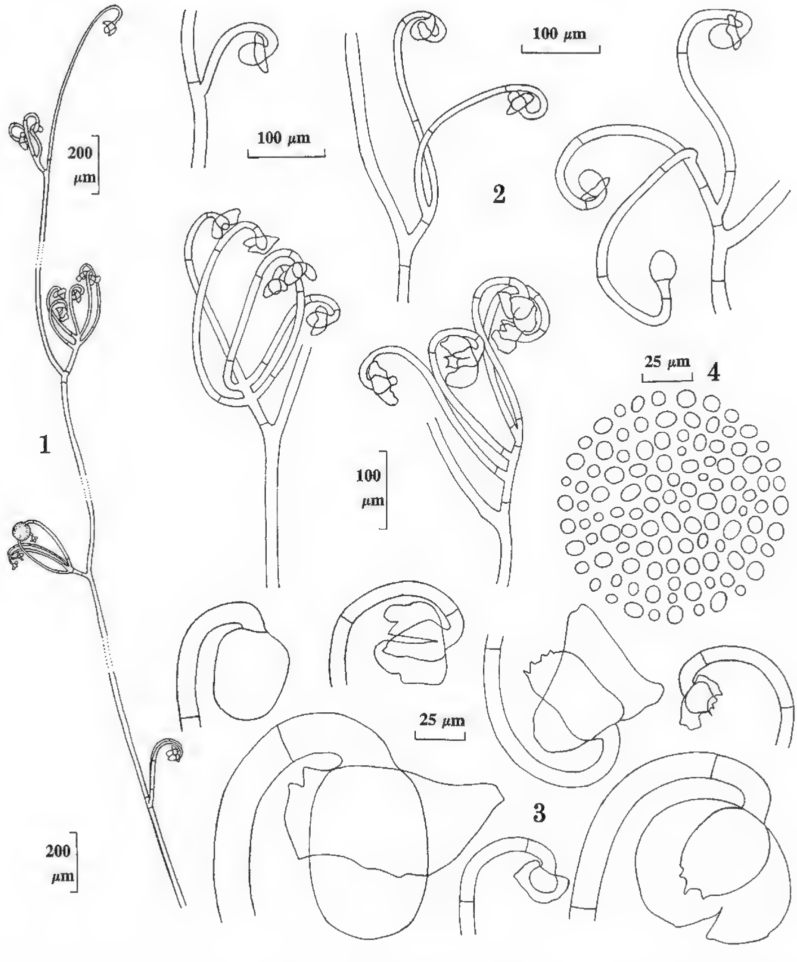

FIG. 4. *Circinella minor* var. *asperior* (C1). 1. General characteristics of the sporophores; 2. Terminal portions of the sporangiophores; 3. Columellae mostly with large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

branching sympodially, main stems (7–)11–23(–27.5) µm diam., branches (5.5–)7–9(–16) µm diam., (47–)82–200(–294) µm long, each branch with a single sporangium or more often terminating into an umbel of 2–5(–6) sporangia, hyaline to pale grayish-brown, 1–2(–4)-septate. SPORANGIA borne on circinate branches, spherical, both terminal and lateral sporangia similar in size, (32–)42–70(–100) µm diam., dark brown color, wall translucent, incrusted and broken. COLUMELLAE broadly ovoid or oblong-ovoid, (14–)27–70 × (15–)23–60 µm, smaller ones roundish conical, 23–46 × 23–55 µm, with 1 to several apical spines, brownish to grayish brown. COLLAR always present. SPORANGIOSPORES globose and 3.5–9(–10.5) µm diam., or ovoid and 5.5–10 × 4.5–9 µm. CHLAMYDOSPORES absent. ZYGOSPORIC STATE not formed between any pair of the (+) and (–) strains found in China under different conditions.

STRAINS STUDIED: CHINA, **HEBEI**, Tianjin City, People's Park, from rabbit dung, 27 May 1965, Zhe-fang Han (C1 = CGMCC 3.14085). **GUIZHOU**, Guiyang, from shrub forest soil, 8 June 1962, Fu-mei Hu (C5 = CGMCC 3.14089). **NINGXIA**, Yinchuan, from pig dung, 19 October 1964, Fu-mei Hu (C17 = CGMCC 3.14101). **BEIJING**, Mentougou, from mouse dung, 26 September 2002, Ji-qi Lu (C27 = CGMCC 3.14111). **LIAONING**, Dalian, December 2013 (C42 (= M.124).

Circinella minor var. *asperior* differs from var. *minor* by having many columellae with verrucae.

Circinella mucoroides Saito, Centralbl. Bakteriol., 2. Abth., 17: 159. 1907. FIG. 5

COLONIES on SMA attaining 9 cm diam. in 8–9 days at 25°C, (2–)5–8(–10) mm high, at first white, becoming Dresden Brown or Buffy Citrine to Cinnamon Brown, Saccardo's Olive after 3 weeks, Antique Brown after 2 months. Reverse Buffy Citrine or Old Gold. Odorless in most strains, rarely with a moldy odor. STOLONS and RHIZOIDS not seen. SPORANGIOPHORES arising from substrate or aerial mycelia, erect, growing indefinitely and branching sympodially from substrate or aerial mycelia, erect, growing indefinitely and branching sympodially, (70–)94–250(–505) µm in length, main stems (4.5–)9–18(–27.5) µm diam., branches (3.2–)6–11(–16) µm diam., each branch with 1(–2) sporangia, hyaline to pale brownish, 1–3-septate. SPORANGIA borne on circinate branches, spherical, terminal ones (21–)35–70(–82) µm, lateral ones similar in size, dark brown color, wall translucent and incrusted, breaking and leaving large pieces of basal collar. COLUMELLAE ovoid, cylindroid or near pyriform and 23–55(–69) × 16–46(–55) µm, globoid and (14.5–)41.5–55 µm, depressed globoid and 18.5–30 × 23–37 µm. SPORANGIOSPORES globose and 3.5–7(–9) µm diam, shortly ovoid and 5.0–7.5 × 4.5–6.5 µm. CHLAMYDOSPORES not seen. ZYGOSPORIC STATE not formed between any pair of the (+) and (–) strains found in China under different conditions.

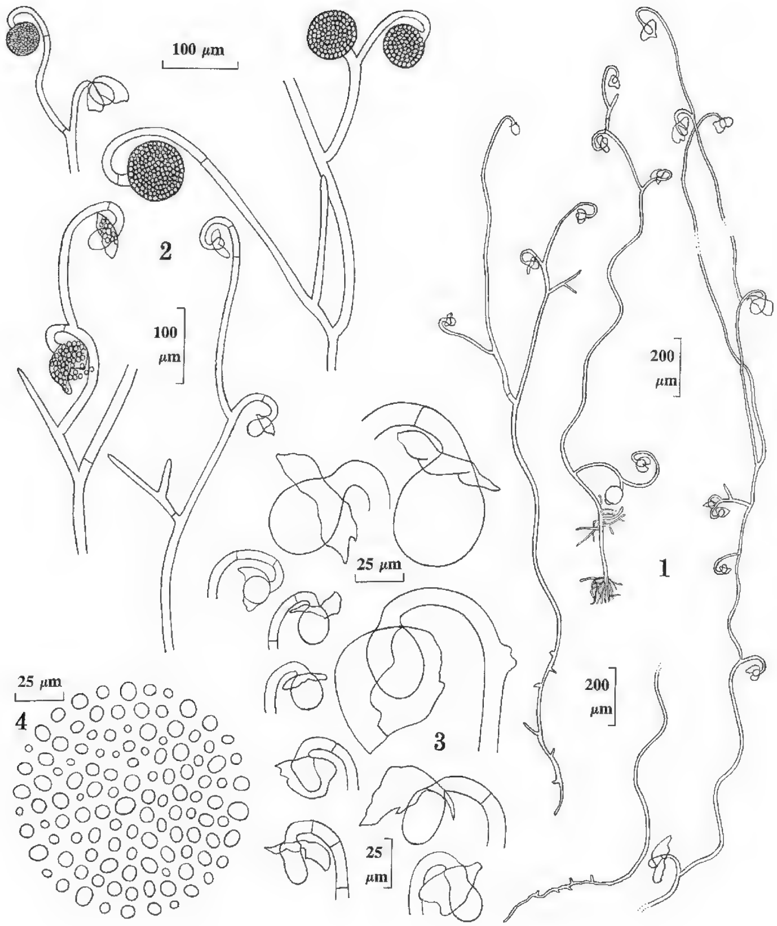

Fig. 5. *Circinella mucoroides* (C6). 1. General characteristics of the sporophores; 2.Terminal portion of the sporangiophores; 3. Columellae with large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

Strains studied: CHINA, **Guizhou**, Xiuwen County, from fallow soil, 21 November 1964, Qing-tao Chen (C2 = CGMCC 3.14086). **Jiangsu**, Nanjing Zoo, from fox dung, 12 October 1960, Xin-sheng Li & Fu-mei Hu (C6 = CGMCC 3.14090). **Zhejiang**, Hangzhou, Zhejiang Agricultural University, from swine dung, 4 September 1987, Gui-qing Chen & Fu-mei Hu (C19 = CGMCC 3.14103); from hen dung, Gui-qing Chen & Fu-mei Hu (C20 = CGMCC 3.14104). **Beijing**, Changping, from vegetable garden soil, 4 May 1982, Ru-yong Zheng (C23 = CGMCC 3.14107); Mentougou, from mouse dung under a walnut tree, 26 September 2002, Ji-qi Lu (C28 = CGMCC 3.14112). **YUNNAN**, Xishuangbanna, from soil under a tree, 9 July 1994, Gui-qing Chen (C26 = CGMCC 3.14110). **INNER MONGOLIA**, Taipushi, from mouse dung, Wei Liu (C29 = CGMCC 3.14113). **TAIWAN**, 26 August 2014, Xiao-man He (C45, received as "*Circinella chinensis*"). **UNKNOWN**, A.F. Blakeslee (C33 [= NRRL 1354]).

Circinella mucoroides is diagnosed by its slightly undulate sporangiophores, simple sterile spines, and sporangia at the upper end of sporangiophores.

Circinella muscae (Sorokīn) Berl. & De Toni, Syll. Fung. 7: 216. 1888. FIG. 6

= *Circinella sydowii* Lendn., Bull. Bot. Genève, Ser. II, 5: 29. 1913.

COLONIES on SMA floccose, attaining 9 cm diam. in 8–10 days at 25°C, 4–8(–10) mm high, at first white, becoming Buffy Citrine or Saccardo's Olive in 7 days, near Walnut Brown in 10 days and Antique Brown to Amber Brown after 2 months. Reverse Sayal Brown, with white to dirty yellow edge surrounded. ODOR absent, rarely with a faint foul smell. STOLONS absent. RHIZOIDS absent or present and branching profusely. SPORANGIOPHORES arising from substrate or aerial mycelia, erect, growing indefinitely and branching sympodially, (6.5–)9–14(–19) µm diam., branches (37–)74–447 µm in length, (4.5–)7–10 µm diam.; fertile branches circinate, with 1 or 2, sometimes 3 sporangia, mostly accompanied by a spine. SPINES simple or dividing 1–2 times, stiff or circinate, recurved, or meandering, (47–)70–141(–376) µm long. SPORANGIA globose to slightly dorsiventrally flattened., 27–60(–82) µm diam., hyaline or translucent when young, dark gray to brown in age, wall persistent, breaking. COLUMELLAE variable in shape, larger ones pyriform, oblong-ovoid, constricted or not constricted at the middle portion, (14–)25–46 × (12–)19–32 µm, smaller ones conical or hemi-globose, (8–)12–30(–37) × (7–)11–25(–32) µm, mostly hyaline, rarely light brown, mostly smooth, a few with spines or protuberances at the apex, often with large pieces of collars attached. SPORANGIOSPORES globose and 3.5–7(–9) µm diam., ovoid and 4.5–7(–11) × 3.5–6.5(–9) µm. ZYGOSPORIC STATE not formed between any pair of the (+) and (–) strains found in China under different conditions.

STRAINS STUDIED: **CHINA**, **GUANGXI**, Guilin, from vegetable soil, Ru-yong Zheng (C13 = CGMCC 3.14097). **HEBEI**, Kailuan, from underground cable, Zu-tong Qi (C21 = CGMCC 3.14105; C22 = CGMCC 3.14106; C24 = CGMCC 3.14108). **SOUTH AFRICA**, **GAUTENG**, Johannesburg, from gold mine soil at a depth of 600 m and 40°C, A. Lendner (C41 [= NRRL 1364 = CBS 107.13, type of *Circinella sydowii*]). **UNKNOWN**, (C34 [= NRRL 1358]; C35 [= NRRL 1359]).

Circinella muscae is characterized by non-undulate sporangiophores and simple spines often associated with sporangiophore branches. Compared

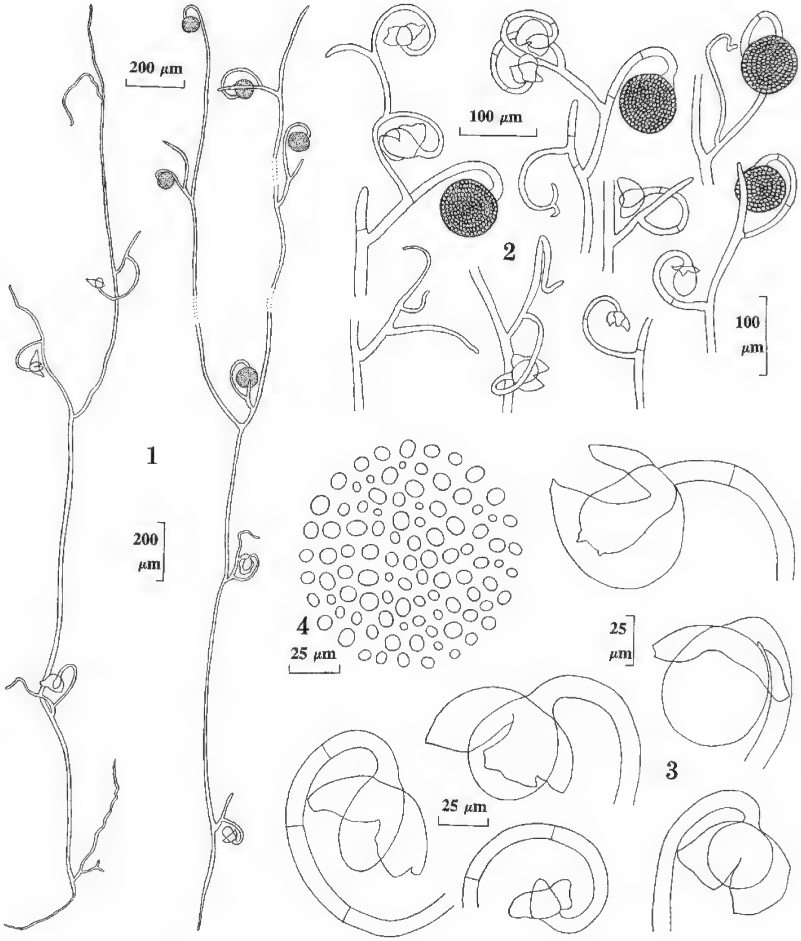

Fig. 6. *Circinella muscae* (C13). 1. General characteristics of the sporophores; 2.Terminal portion of the sporangiophores; 3. Columellae mostly with smooth apices and with large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

with its allied *C. mucoroides,* this species produces more deeply colored sporangiophores, fewer sterile spines, shorter and more circinate branches, and smaller sporangia.

Circinella nodulosa R.Y. Zheng, X.Y. Liu & Y.N. Wang, **sp. nov.** Fig. 7

Fungal Name FN570151

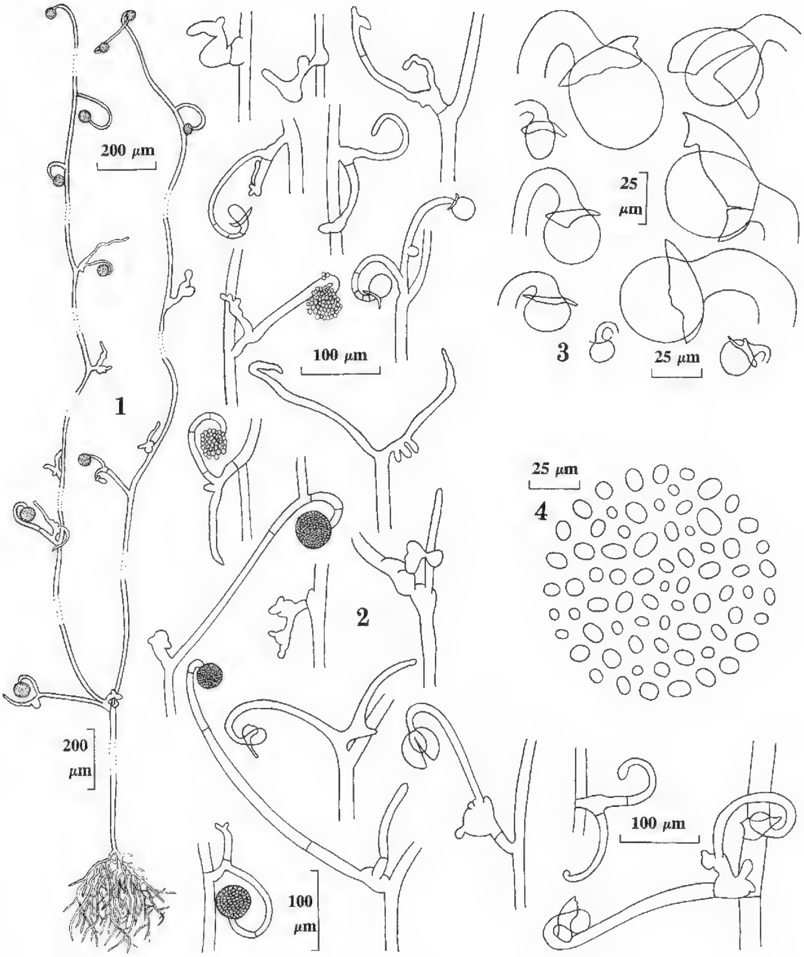

Fig. 7. *Circinella nodulosa* (C18). 1. General characteristics of the sporophores; 2. Terminal portion of the sporangiophores; 3. Columellae with small or large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

Differs from other species of *Circinella* by forming unbranched nodulose structures at the base of sporangiophores or spines.

Type: People's Republic of China, Zhejiang Prov., Hangzhou, campus of Zhejiang Agricultural University, from sheep dung, 4 September 1987, Gui-Qing Chen & Fu-Mei Hu (**Holotype** HMAS 245380; ex-holotype culture CGMCC 3.14102 = C18).

Etymology: *nodulosa*, nodular, referring to the nodulose nature of the special structure forming at the base of spines.

Colonies on SMA floccose, attaining 9 cm diam. in 7–9 days at 25°C, about 10 mm high, at first white, becoming Yellow Ocher to Ochraceous Tawny in the central part, remaining white in the periphery. Reverse pale yellowish. Odorless. Stolons absent. Rhizoids abundant. Sporangiophores arising from the substrate or aerial mycelia, erect, growing indefinitely and branching sympodially, 59–450 µm in length; main stems 9–23(–50.5) µm diam., branches 4.5–11.5(–16) µm diam., each branch with 1(–2) sporangia, 1–3(–5)-septate on the branches, usually without septation on the main stems, nodulose outgrowths may appear on the main stems or the branches of the sporangiophores, especially at the base of the branches or spines. Sporangia borne on circinate branches, globose, 26–47 µm diam., light grayish brown to pale yellowish-brown or subhyaline, breaking and leaving a large collar. Columellae ovoid, 18.5–41.5(–50.5) × 16–32(–41.5) µm, globose to subglobose, 16–55 µm diam., smaller ones depressed-globose, 9–18.5 × 14–23 µm, pale to light brown. Collars small to large, usually without, but sometimes with apophyses. Sporangiospores ovoid and 5.5–9(–10) × 4–7.5(–8.5) µm, rarely reaching 12.5 × 9 µm, globose and (4.5–)5.5–7(–8) µm diam., hyaline. Zygosporic state not formed between any pair of the (+) and (–) strains found in China under different conditions.

Circinella ramosa R.Y. Zheng, X.Y. Liu & Y.N. Wang, **sp. nov.** Fig. 8

Fungal Name FN570150

Differs from other species of *Circinella* by sometimes forming, at the base of spines, a rhizoid-like structure that branches irregularly several times or is otherwise contorted.

Type: People's Republic of China, Inner Mongolia, from spinach field soil, June 1962, Xun-Chu Yan (**Holotype** HMAS 245379; ex-holotype culture CGMCC 3.14088 = C4).

Etymology: *ramosa*, from the Latin *ramosus* (branched), pertaining to the branched special structure forming at the base of spines.

Colonies on SMA attaining 9 cm in 7–9 days at 25°C, (2–)5–10 mm high, at first white, becoming Dark Citrine after 7 days in the central portion, or Saccardo's Olive after 20 days, with a white periphery which disappearing after 3 weeks. Reverse among Aniline Yellow and Orange Citrine in 7 days, 2–5 mm high. Near Odorless. Stolons absent. Rhizoids abundant and branching profusely at the base of the main stem. Sporangiophores arising from the substrate or aerial mycelia, erect, growing indefinitely and branching sympodially, curved to helicoids, (82–)141–400(–610) µm in length, main stems (8–)10–20.5(–25) µm diam., branches (4.5–)7–11.5(–13) µm diam., each branch with 1(–3) sporangia, or without sporangia and substituted by a

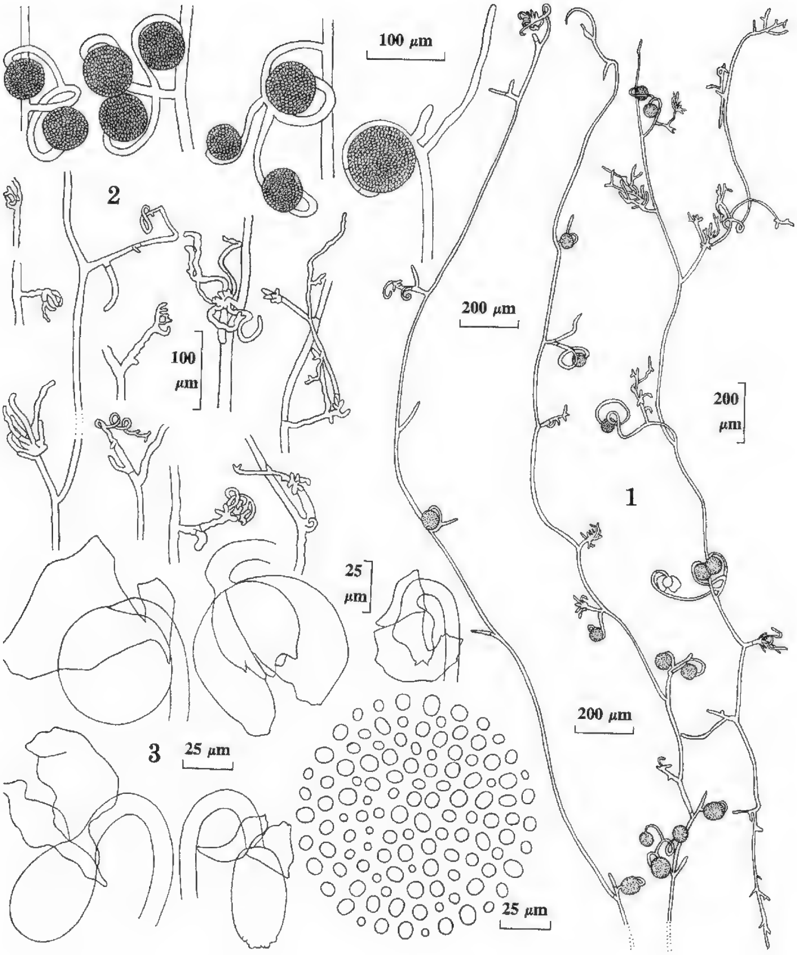

Fig. 8. *Circinella ramosa* (C4). 1. General characteristics of the sporophores; 2. Terminal portion of the sporangiophores; 3. Columellae with large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

rhizoid-like structure that branches irregularly several times or is contorted. Sporangia subhyaline, brownish to dark brown, somewhat depressed globose or spherical, (19–)33–75(–82) µm diam., broken after mature, collar large or small. Columellae ovoid, cylindroid, rarely pyriform, (18.5–)28–64(–74)

× (13–)30–48(–69) µm, or globose and (18.5–)27.5–46(–55) µm diam., upper most portion of the sporangiophores just beneath the sporangia often widened and apophyses-like. SPORANGIOSPORES ovoid and 4.5–9 × 3.5–8 µm, or globose and 3.5–7 µm diam., pale yellowish gray when single, gray color in mass. ZYGOSPORIC STATE not formed between any pair of the (+) and (–) strains found in China under different conditions.

ADDITIONAL STRAINS STUDIED: **CHINA**, **GUANGDONG**, Yingde, from soil under grasses, 4 October 1960, Ru-yong Zheng (C7 = CGMCC 3.14091). **YUNNAN**, Yuanjiang, from dog dung, 21 May 1963, Zao-yuan Zhang & Yong-gui Ma (C10 = CGMCC 3.14094). **HAINAN**, Chuangjiang, Cha River, from soil at river bottom, Dong-hai Ye (C14 = CGMCC 3.14098).

Circinella simplex Tiegh., Ann. Sci. Nat., Bot., 6e sér., 1: 92 (1875). FIG. 9

COLONIES on SMA attaining 6.7 cm in 6 days at 25°C, at first white, 5–8 mm high, then submerged in the central portion, with a brownish zone which disappear after 3 weeks, Deep Olive-Buff to Dark Olive-Buff after 20 days, 2–3 mm high. Reverse Pale Olive-Buff. Near odorless. STOLONS absent. RHIZOIDS absent. SPORANGIOPHORES arising from the substrate, erect, hyaline to pale brownish, growing indefinitely and branching sympodially, curved, (5–)8–12.5(–16) µm diam., branches slightly widening near the basal parts, (13.5–)31–68(–114) µm in length, each branch with one sporangium, branches (0–)1(–2)-septate, spines absent. SPORANGIA spherical, (27.5–)32–61.5(–69) µm diam., at first hyaline, then brown, deliquescing after broken. Collar small or absent. COLUMELLAE variable in shape, broadly ovoid, cylindroid or near pyriform, constricted or not constricted at the middle portion and (11–)14.5–37.5 (–44.5) × (7–)12.5–27.5(–41) µm, depressed globoid to conical and (5.5–)12.5–23 (–33) × (7–)14–25(–41) µm, mostly hyaline, the larger ones light brown, mostly smooth, a few with 1 to several spines at the apex. SPORANGIOSPORES very irregular in shape, mostly 3.5–9 × 2–7 µm, larger ones 10–16.5 × 4–5 µm diam., with conspicuous oil droplets, hyaline. CHLAMYDOSPORES nearly spherical, 16–29 µm diam., each containing one larger or several small droplets, elongated on substrate mycelia. ZYGOSPORIC STATE not formed.

STRAINS STUDIED: **CHINA**, **TAIWAN**, Taibei, from soil (C44 [= BCRC FU30085]). **BRAZIL**, from soil (C46 [= BCRC 31711 = CBS 142.35 = IFO 6412 = IMI 252490 = NRRL 2407]).

Circinella simplex has the typical morphological characteristics of this genus, circinate branches bearing sporangia with persistent walls, and was recognized by producing irregular sporangiospores.

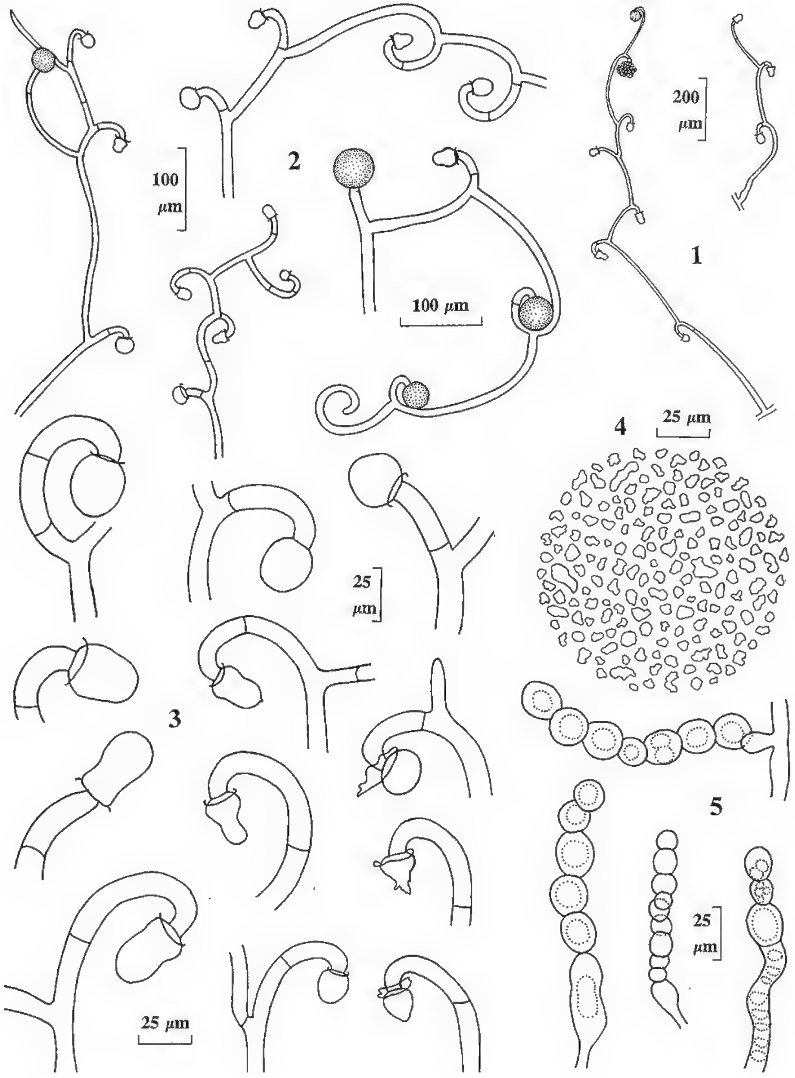

FIG. 9. *Circinella simplex* (C44). 1. General characteristics of the sporophores; 2. Terminal portion of the sporangiophores; 3. Columellae with small or large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores; 5. Chlamydospores.

Circinella umbellata Tiegh. & G. Le Monn.,
Ann. Sci. Nat., 5e sér., 17: 300. 1873. FIG. 10

= "*Circinella chinensis*" H. Nagan. &Kojiro, J. Ferm. Tech. 20: 409. Pl. 3. 1942, nom. inval.

COLONIES on SMA attaining 9 cm diam. in 7–9 days at 25°C, (3–)7–10 mm high, at first white, Old Gold or Isabella Color in 7 days, Light Brownish Olive to Cinnamon Brown in 2 weeks, then Hazel to Antique Brown after 2 months. Reverse similar to the obverse side or dirty grayish brown. STOLONS and RHIZOIDS absent. SPORANGIOPHORES arising from the substrate or aerial mycelia, erect, growing indefinitely and branching sympodially, (82–)130–258(–282) µm in length, main stems (9–)14–27.5(–33) µm diam., branches (5.5–)7–14(–18.5) µm diam., each branch with a single sporangium or more often terminating into an umbel of 2–12 SPORANGIA borne on circinate branches which are hyaline to somewhat brownish and (0–)1–2-septate, spherical, (27–)41–94(–118) µm diam., dark brown color, wall translucent, incrusted and breaking. COLUMELLAE ovoid, oblong-cylindroid, or pyriform and (23–)30–60(–74) × (18.5–)24–46(–64.5) µm, or globose and (18.5–)27.5–50.5(–69) µm diam. in the larger ones, depressed-globose to conical and (9–)18.5–41.5(–69) × (14–)23–46(–59) µm in the smaller ones, mostly smooth, a few with 1 to several spines at the apex, brownish or light grayish-brown. SPORANGIOSPORES globose, (4.5–)5.5–10 µm diam., or ovoid, (6–)7–11(–12.5) × (5.5–)6.5–10(–11) µm, easy to germinate and becoming irregular in shape. ZYGOSPORIC STATE not formed.

STRAINS STUDIED: **CHINA**, **BEIJING**, Zhongguancun, from mouse dung, 8 June 1961, Fu-mei Hu (C9 = CGMCC 14093). **HUNAN**, Hengyang, Yueping Park, from soil, 17 June 1963, Ru-yong Zheng & Fu-mei Hu (C12 = CGMCC 3.14096). **INNER MONGOLIA**, Arshaan, Yiershi, from wilted *Rhododendron* flower, 23 June 1963, Xi-ling Chen (C15 = CGMCC 3.14099). **HAINAN**, Limu Mountain, from soil under jackfruit plant, Song Lin (C25 = CGMCC 3.14109). **JAPAN** (C40 [= NBRC 4453 = CBS 140.28, type of "*Circinella chinensis*"]). **UNKNOWN**, A.F. Blakeslee (C36 [= NRRL 1351 = CBS 144.56]; from dog dung (C37 [= NRRL 1366 = CBS 145.56]).

Circinella umbellata, the type species for *Circinella,* differs from other species in the genus in its sporangiophores that terminate in an umbel of 2–12 sporangia. *Circinella "chinensis"*, which was published by Naganishi & Kojiro (1942) without a Latin diagnosis, was treated by Hesseltine & Fennell (1955) as a synonym of *C. mucoroides*. Naganishi (1974), however, pointed out sporangiophore differences by comparing the Osaka strain (IFO 4455) of *C. mucoroides* and Dairen strain (NRRL 1354) of *C. chinensis*. Our study of the ex-type of *C. "chinensis"* reveals that morphologically it belongs to *C. umbellata.*

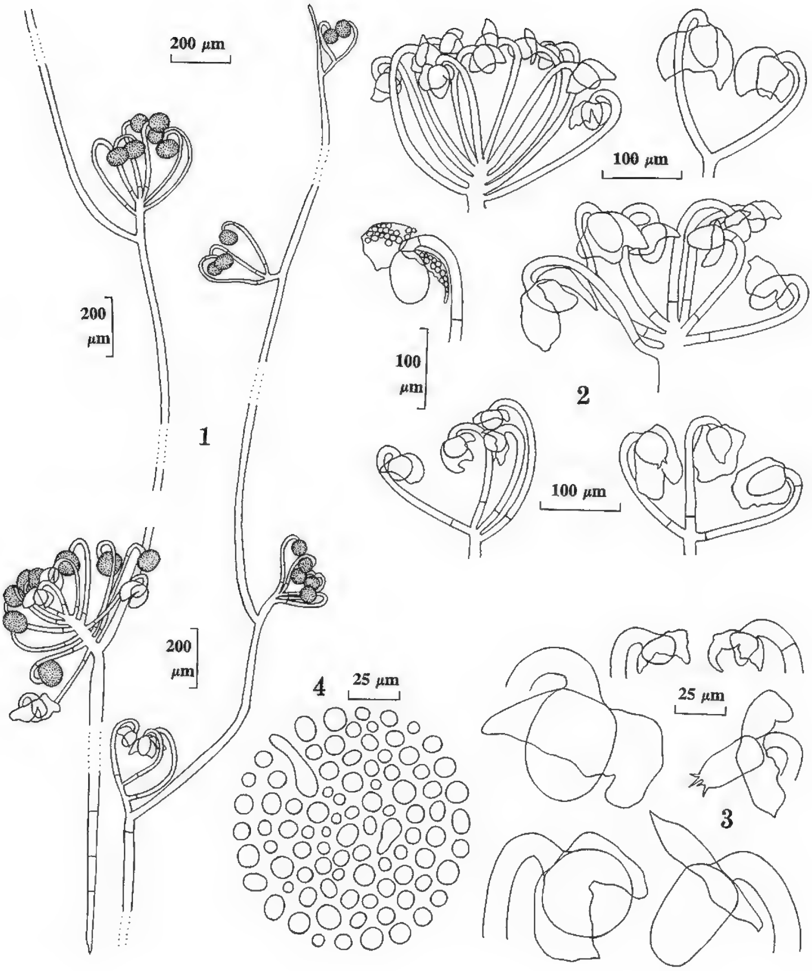

FIG. 10. *Circinella umbellata* (C9). 1. General characteristics of the sporophores; 2.Terminal portion of the sporangiophores; 3. Columellae usually with large pieces of the basal part of the sporangial wall attached; 4. Sporangiospores.

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Literature cited

Arambarri AM, Cabello MN. 1996. *Circinella lacrymispora* sp. nov. A new mucoral isolated from Argentine soils. Mycotaxon 57: 145–149.

Benny GL, Benjamin RK. 1975. Observations on *Thamnidiaceae* (*Mucorales*). New taxa, new combinations, and notes on selected species. Aliso 8(3): 301–351.

Benny GL, Schipper MAA. 1992. Observations on *Thamnidiaceae* (*Mucorales*). IV. *Pirella*. Mycologia 84: 52–65. http://dx.doi.org/10.2307/3760401

Faurel L, Schotter G. 1965. Notes mycologiques VI. Sur quelques champignons coprophiles d'Afrique Equatoriale. Cah. La Maboke 3: 123–133.

Hesseltine CW, Fennell DI. 1955. The genus *Circinella*. Mycologia 47: 193–212. http://dx.doi.org/10.2307/3755410

Mil'ko AA. 1968. [The nomenclature of some *Mucorales* with diagnostic keys to species of *Circinella, Thamnidium* and *Kickxella*.] Novosti Sist. Nizsh. Rast. 5: 79–88. [In Russian]

Mil'ko AA. 1969. [A new species of the genus *Circinella* van Tieghem et Le Monnier.] Novosti Sist. Nizsh. Rast.6: 96–102. [In Russian]

Mil'ko AA. 1974. Opredeltiel mukoral nykh gribov. Naukova Dumka, Kiev. 303 p. [In Russian]

Naganishi H. 1974. On *Circinella* species isolated from Korean yeast cake (Kyokusi). Trans. Mycol. Soc. Japan 15:175-177.

Naganishi H, Kojiro K. 1942. *Circinella*. Jour. Ferm. Tech. 20:408-414. [In Japanese]

Patil SD, Kale JC. 1981. A new species of *Circinella* van Tiegh. and Le Monn. Current Science 50(12): 544.

Ridgway R. 1912. Color standards and nomenclature. The Author, Washington D.C. 44 pp., 53 colored plates.

Tai FL. 1979. Sylloge Fungorum Sinicorum. Science Press. 1527 p.

Teng SC. 1964. Fungi of China. [RP Korf (ed.)]. Mycotaxon Ltd., Ithaca, New York. 586 p.

van Tieghem P, Le Monnier G. 1873. Recherches sur les Mucorinées. Ann. Sci. Nat., Bot. 5e sér., 17: 261–399.

Walther G, Pawłowska J, Alastruey-Izquierdo A, Wrzosek M, Rodriguez-Tudela JL, Dolatabadi S, Chakrabarti A, de Hoog GS. 2013. DNA barcoding in *Mucorales*: an inventory of biodiversity. Persoonia 30: 11–47. http://dx.doi.org/10.3767/003158513X665070

Warcup JH. 1950. The soil-plate method for isolation of fungi from soil. Nature 166: 117–118. http://dx.doi.org/10.1038/166117b0

Xiao BX, Ho HM, Liu GY. 2013. Studies on the taxonomic and phylogenetic relationship of the genus *Circinella* (*Mucorales*) from Taiwan Prov. of China. p. 13, in: Eleventh Cross-Taiwan Straits Joint Symposium for Mycology, 17–19 August, 2013. Beijing. [In Chinese; this citation translated into English by RY Zheng]

Yang BY, Liu CH. 1972. Preliminary studies on Taiwan *Mucorales* (I). Taiwania 17(3): 293–303.

Zycha H. 1935. *Mucorineae.* In Kryptogamenflora d. Mark Brandenburg 6a: 1-264.